United States Patent [19]

Smith

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[54] **OPTICAL PROXIMITY DETECTOR**

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[73] Assignee: **The United States of America as represented by the Secretary of the Navy**, Washington, D.C.

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[51] **Int. Cl.**[5] **F42C 13/02**

[52] **U.S. Cl.** **102/213**

[58] **Field of Search** 102/213

[56] **References Cited**

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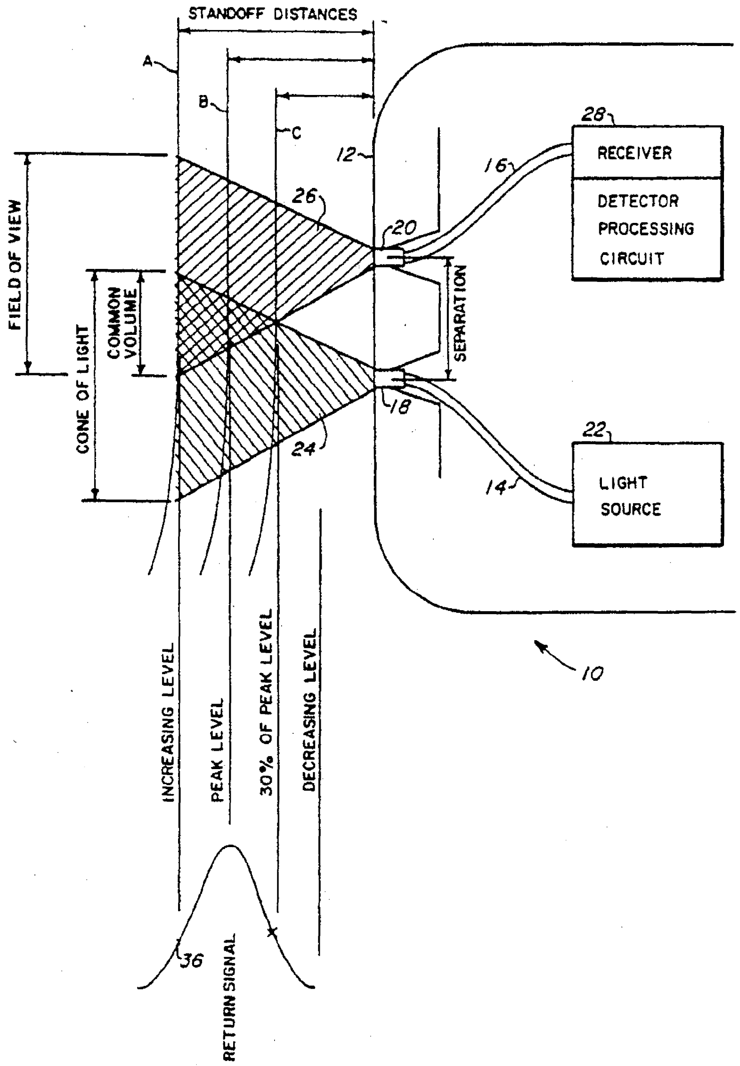
[57] **ABSTRACT**

Method and apparatus for optically detecting an object within close proximity to a structure surface, e.g., the nose of a torpedo or claw of a robotic arm, and generating a responsive control or command signal. A cone of light is emitted from the structure surface to illuminate any object coming within its field. Light reflected from that object to a receiver is processed to generate a responsive first electrical signal. This first signal is further processed to generate a second signal, control or a command signal, only after the first signal has decreased to around 30% of its peak level indicating that the object has closed to within a predetermined distance to the structure surface.

11 Claims, 4 Drawing Sheets



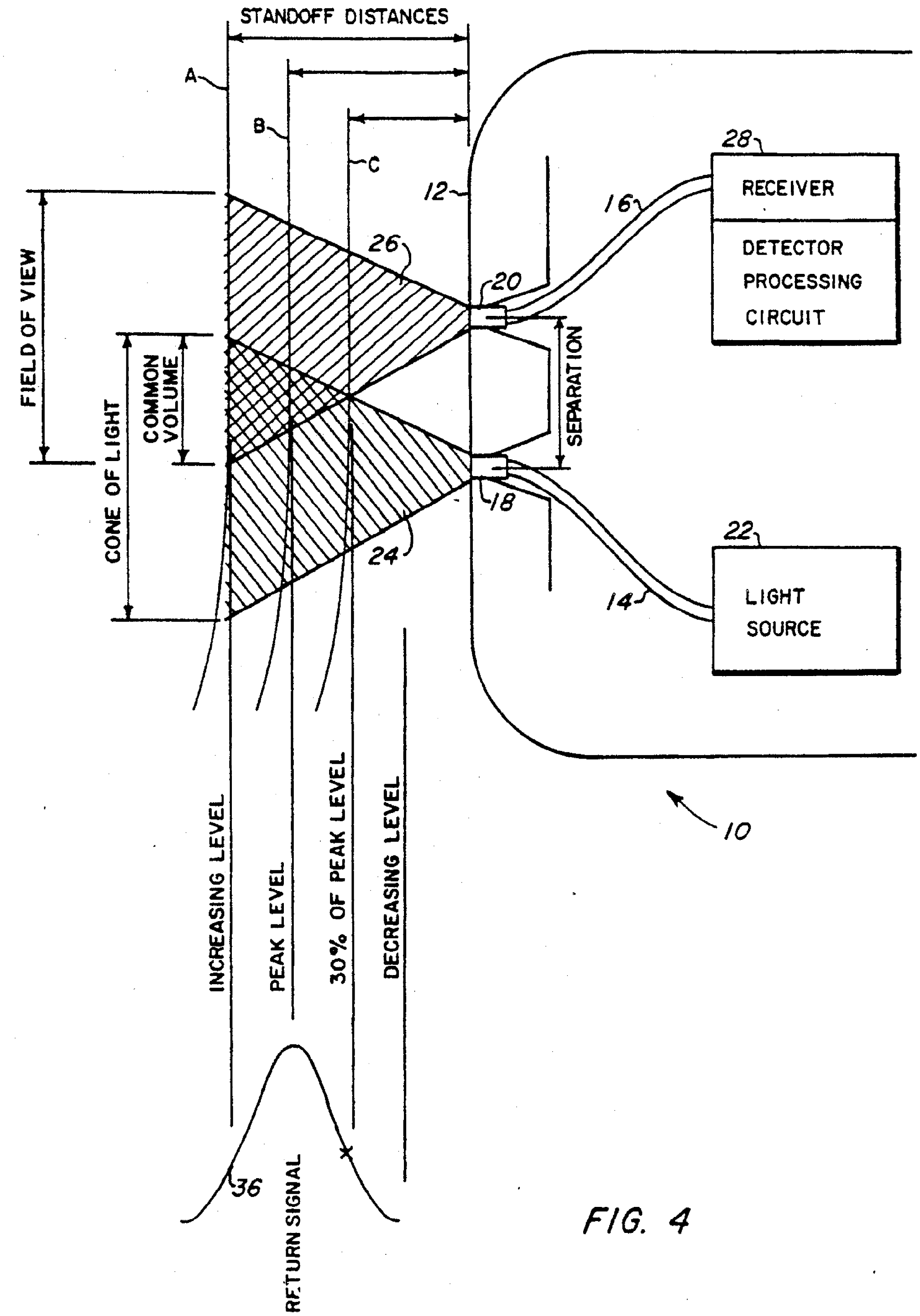

STANDOFF DISTANCES
A
B
C
12
28
RECEIVER
DETECTOR
PROCESSING
CIRCUIT
16
26
20
FIELD OF VIEW
CONE OF LIGHT
COMMON VOLUME
SEPARATION
18
22
24
14
LIGHT
SOURCE
10
INCREASING LEVEL
PEAK LEVEL
30% OF PEAK LEVEL
DECREASING LEVEL
36
RETURN SIGNAL

FIG. 4

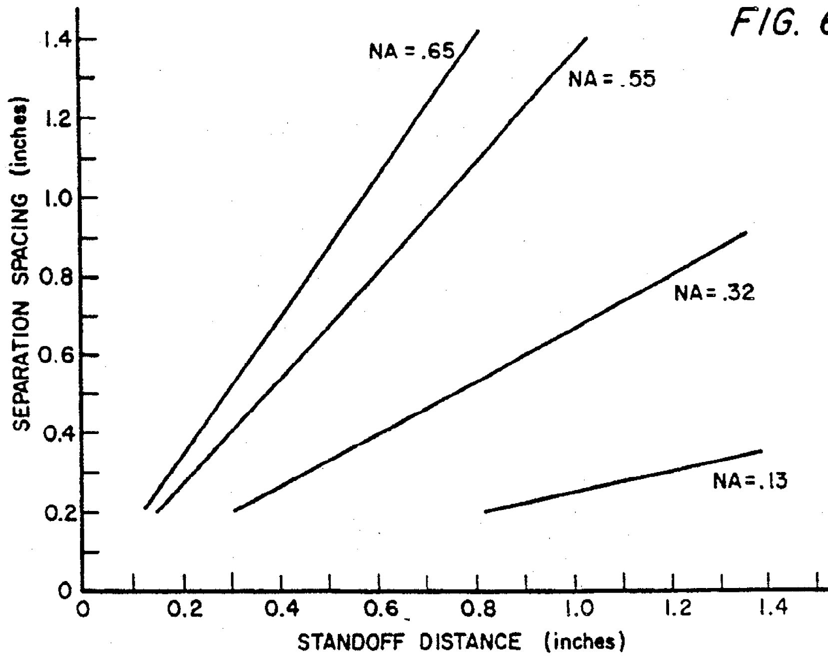

NA = .65
NA = .55
NA = .32
NA = .13
SEPARATION SPACING (inches)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
STANDOFF DISTANCE (inches)

FIG. 6

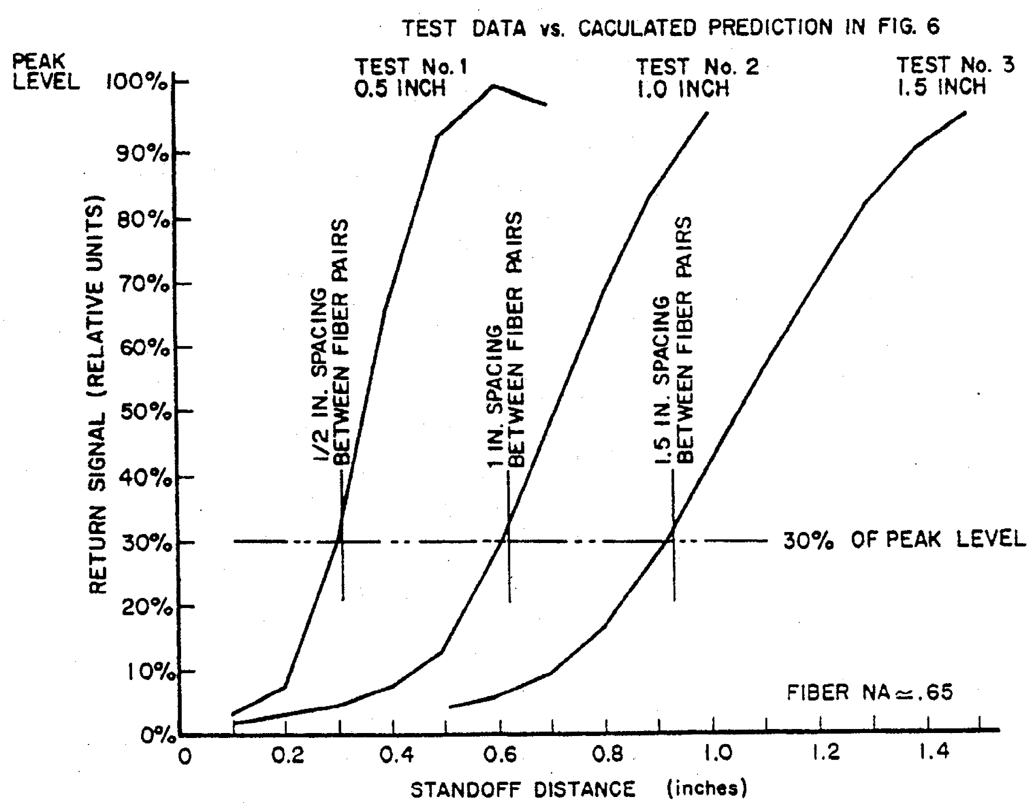

TEST DATA vs. CACULATED PREDICTION IN FIG. 6
PEAK LEVEL
TEST No. 1
0.5 INCH
TEST No. 2
1.0 INCH
TEST No. 3
1.5 INCH
RETURN SIGNAL (RELATIVE UNITS)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1/2 IN. SPACING BETWEEN FIBER PAIRS
1 IN. SPACING BETWEEN FIBER PAIRS
1.5 IN. SPACING BETWEEN FIBER PAIRS
30% OF PEAK LEVEL
FIBER NA ≃ .65
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
STANDOFF DISTANCE (inches)

FIG. 7

FIG. 6 illustrates in graph form calculated predictions of standoff distances for the optical proximity detector versus numerical apertures (NA) and separation spacing between sending and receiving optical fiber ends.

FIG. 7 is actual test results in graph form illustrating the magnitude of the return (reflecting) signal for a fiber having a numerical aperture equal 0.65 at three different standoff distances.

DETAILED DESCRIPTION OF THE INVENTION

Refer now to the drawings for a more detailed presentation of the invention. There is shown in FIG. 1 a schematic illustration of a pair of optical proximity detectors applied to the gripper claw a robotic arm In FIG. 2 the optical proximity detector is applied to the nose of a torpedo shown approaching the hull of a submarine or ship.

While the invention has numerous applications for detecting objects approaching to within close proximity to a structure surface, detailed description will be made herein concerning its use on a torpedo nose. Accordingly, in FIG. 4, the invention is disclosed within a setting of a torpedo, identify generally by numeral **10**, having a nose structure with a flat frontal surface **12**. A pair of optical fibers **14** and **16** have respective ends **18** and **20** terminating substantially flush with the frontal surface and facing in a parallel forward direction. Light source **22**, such as light emitting diode, incandescent bulb or a laser diode, is coupled into the other end of optical fiber **14**. Its light, once launched into the optical fiber, is transported along the optical fiber until it reaches end **18** where it exits in the form of cone **24** to illuminate the surface of any object (target) which may come within its field of view. The exit angle of the light cone is known as the numerical aperture (NA), or cone of acceptance, and its magnitude depends upon several factors. These include the index of refraction of the optical fiber core (N_1), core cladding (N_2) and the medium (N_0) into which the light exits. The angle of the exit cone is equal to 2 arcsine NA/N_0. Where $N_1^2-N_2^2$ is define as the numerical aperture. In air ($N_0=1$) and the equation for the exit cone angle reduces to 2 arcsine NA). By choosing the type of optical fiber, the exit cone angle can be controlled.

Light emitted from end **18** of optical fiber **14** (transmitting) traverses the medium (water) in front of it to illuminate a target, the surface of which is illustrated at standoff distances A, B, and C in FIG. 4. Light striking the target in any of these positions, or ones intermediate thereof, is reflected back in many directions, including to input end **20** of receiving optical fiber **16**. Light striking fiber end **20** (within its cone of acceptance or field of view **26**, 2 arcsine NA) is transported along receiving optical fiber **16** to receiver **28** (photodetector) located at its other end. Reference should now be made to FIG. 5 for description of the electronic processing circuit. Photodetector **28** (photo diode) converts the light into an electrical signal which is buffered (amplified) to provide a first electrical signal **30**. This first electrical signal is then processed by the detector processing circuit illustrated diagramatically in FIG. 5 Buffered signal **30** is applied to a peak detector **32** which provides signal **34**. The output of the peak detector is multiplied by 0.3 at the scaler and then compared to buffer signal **30**. When signal **30** has decreased to 30% of the value of peak detector **34** a second signal is generated to indicate detection of a target and provide a control or command signal to fire an explosive charge (not illustrated) within the torpedo.

As will be appreciated from a study of the illustration in FIG. 4, the standoff distances at which the disclosed apparatus can detect a target (e.g., A, B, or C) varies in accordance with the lateral separation distance between optical fiber ends **18** and **20**. The closer the optical fiber ends are to each other, for example, the closer to the torpedo nose structure surface the field of "common volume" commences. The greater the separation distance the further out the cone of common volume commences. Another factor controlling commencement of the field of common volume and standoff distance at which the detecting apparatus is effective is the numerical aperture (NA) of the optical fiber ends. This defines the angle of emitted cone of light from end **18** and the cone of acceptance defining the field of view of receiving optical fiber end **20**.

It will be appreciated that light (both emitted and reflected) is dissipated in passing through water forward of the torpedo nose surface **12**. Therefore, there is a practical limit to the standoff distance at which the invention arrangement is effective. With the arrangement illustrated in FIG. 4, the practical standoff distance from the torpedo nose at which an explosive carried by the torpedo can be initiated is from a fraction of an inch to several inches.

FIG. 6 shows the relationship between the standoff distance and the separation spacing between transmitter optical fiber end **18** and receiving optical fiber end **20** for four different optical fibers having numerical aperatures ranging from 0.13 to 0.65. FIG. 7 illustrates the results of a series of test. The standoff distances are shown at the 30% level. In test #1, the transmitting and receiving optical fiber ends **18** and **20** were 0.5 inches apart. For test #2 the separation was 1.0 inches, and for test #3 the separation was 1.5 inches. The returned signal (normalized) was plotted. In each test, the signal level was approximately 30% of its peak value at the calculated standoff distance.

Referring once again to FIG. 4, it will be noted that the cone of emitted light **24** and the field of view defined by the cone of acceptance **26** overlap to provide a common volume commencing a short distance in front of the torpedo nose structure surface. It is within the field of this common volume that an illuminated object's reflected light will be accepted by optical fiber end **20**. Three standoff distances (A, B, or C) are illustrated in this field of common volume. Further out than standoff distance A, so much light is absorbed by the medium (water) that no reflected light is indicated. However, for an object or target coming within standoff distance A there is produced an increasing level of reflected light as indicated by signal curve **36**. While more of the target surface reflects light when the target is farther out much light is dissipate in transmission in both out and return legs which may range up to several inches. As the standoff distance closes from position A, the magnitude of reflected light increases rapidly as indicated by the rising portion of curve **36**. At target standoff distance B the light reflected to optical fiber end **20** is at its peak level. As the target standoff distance closes still further, the level of light reflected rapidly decreases, and at standoff distance C (where the field of common volume commences), reflected light is at around 30% of the peak level at standoff distance B. As the target closes

2. The invention according to claim 1 further defined by the structure surface being the surface of a robotic grasping claw.

3. The invention according to claim 1 further defined by the structure surface being the nose surface of a torpedo.

4. The invention according to claim 2 further defined by the optical fiber first ends terminating substantially adjacent the structure surface of the robotic grasping claw.

5. The invention according to claim 3 further defined by the optical fiber first ends terminating substantially adjacent the structure surface defining the forward nose surface of a torpedo.

6. A proximity detector for use on a torpedo for detecting the surface of an underwater object being approached by the torpedo nose, comprising:

at least one pair of optical fibers having first ends terminating adjacent the nose surface and facing optically forward thereof;

said optical fiber first ends spaced apart a selected lateral distance so that their cones of acceptance mutually overlap commencing a short distance in front of the nose surface to define a common volume;

one of the optical fibers coupled with a light source for emitting light from its first end for illuminating the surface of an underwater object ahead of the torpedo in its cone of acceptance;

the other of the optical fibers adapted to receive in its cone of acceptance light reflected from the surface of the underwater object coming within the common volume of the cones of acceptance and transport that light to its other end;

means detecting the transported reflected light at the fiber end and converting it to a responsive first electrical signal; and,

means processing the first electrical signal and providing a second electrical signal only after the first electrical signal has decreased to approximately 30% of its peak level;

whereby the second electrical signal defines a signal for firing a warhead aboard the torpedo only after the approached object surface has become closer to the torpedo nose surface than in the common volume where maximum light reflection is received.

7. The invention according to claim 6 further defined by the first ends of the optical fiber pair terminating substantially flush with the torpedo nose surface.

8. The invention according to claim 7 further defined by a plurality of pairs of optical fibers disposed about the torpedo nose.

9. The invention according to claim 8 further defined by optical fiber pairs having their ends spaced apart different distances thereby controlling the short distance to the cones of acceptance common volume.

10. The invention according to claim 8 further defined by different optical fiber pairs having different cones of acceptance.

11. A method of detecting the presence of an object in close proximity in front of a structure surface comprising the steps of:

emitting a cone of light in front of the structure surface for illuminating any object coming within its field;

receiving light reflected from the illuminated object along a cone of acceptance which partially overlaps with the cone of emitted light commencing shortly in front of the structure surface to define a common volume;

generating a first electrical signal responsive to the magnitude of light reflected from an object coming within the field of the common volume; wherein said first electrical signal increases to a peak level as the object approaches into the common volume and decreases as the object departs the common volume; and,

processing the first electrical signal to provide a second electrical signal only after the first electrical signal has decreased to substantially below its peak level.

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